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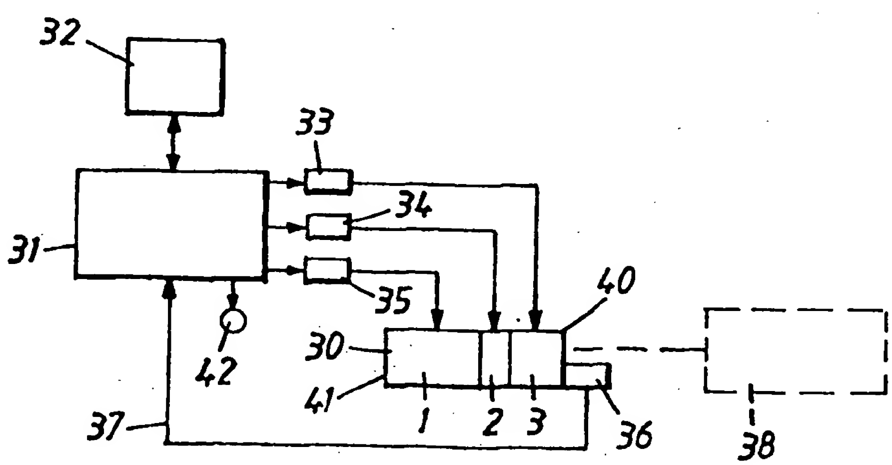
(57) Abstract



A method of optimising the operation point of a laser, comprising characterising the laser and controlling the different laser sections. The invention is characterized by controlling the different laser sections (1, 2, 3) by varying the current injected into respective sections; causing the laser (30) to be sensed with respect to discontinuities occurring at mode jumps in a signal from a detection device firmly connected to the laser; effecting the control of the different laser sections (1, 2, 3) by means of a control unit (31); delivering different control combinations and the signal delivered from the detection device to the control unit (31); causing the control unit to detect the mode plane of the laser (30); storing at least a part of a mode plane or several mode planes in a memory (32) belonging to the control unit (31); and causing the control unit (31) to control different laser sections (1, 2, 3) such that the laser will obtain the desired operation point.

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Method of optimizing the operation points of lasers and means for carrying out the method.

The present invention relates to a method of optimising the operation points of lasers, and also to means for this end. More specifically, the invention relates to a method of optimisation that does not require the aid of external equipment as a reference.

Tuneable semiconductor lasers include several different sections through which current is injected. The lasers typically have three or more sections. The wavelength, power and mode purity of the lasers can be controlled, by adjusting the current injected into the various sections. Mode purity implies that the laser shall be tuned to an operation point, i.e. tuned to a combination of the three or four injected drive currents, which is characterized in that the laser is distanced from a combination of the drive currents where so-called mode jumps take place and where lasering is stable and where sidemode suppression is high.

Special wavelength controls are required with different applications. For instance, in the case of sensor applications it must be possible to tune the laser continuously, so as to avoid mode jumps as far as possible. In the case of telecommunications applications, it is necessary that the laser is able to retain its wavelength to a very high degree of accuracy and over very long periods of time, after having set the drive currents and the temperature. A typical accuracy in this respect is 0.1 nanometer while a typical time period is twenty years.

In order to be able to control the laser, it is necessary to map the behaviour of the laser as a function of the various drive currents. This is necessary prior to using the laser after its manufacture. However, it is also necessary to discern degradation of a laser in operation and to be able to compensate for this degradation by changing the drive currents. A change in the wavelength for a given operation point is an example of such degradation.

Mapping of the behaviour of a laser is normally effected by connecting the laser to different measuring instruments and then varying the drive currents systematically. Such instruments are normally power meters, optical spectrum analysers for measuring wavelength and sidemode suppression, and line width measuring devices. This laser measuring process enables all of these parameters to be fully mapped as a function of all different drive currents.

However, the process has decisive drawbacks. The measuring processes are highly time-consuming and also generate large quantities of unnecessary data. It is not until the laser has been measured-up that suitable areas of operation can be discerned. Furthermore, an additional wavelength reference, for instance an optical spectrum analyser or wavelength measuring device, is required in order to carry out the measurements. This makes it difficult to subsequently check or adjust the setting and/or the calibration of lasers that have already been installed in operation.

The present invention eliminates these drawbacks.

The present invention thus relates to a method of optimising the operation point of a laser, comprising characterising the laser and controlling the various sections of said laser, wherein the method is characterised in that the different sections of the laser are controlled by varying the injected currents; in that the laser is sensed with respect to discontinuities occurring in mode jumps in a signal delivered by a sensing device firmly connected to the laser; in that control of the various laser sections is effected with the aid of a control unit; in that different control combinations and the signal delivered by the sensing device are sent to said control unit; in that the control unit is caused to detect the mode plane of the laser; in that at least a part of a mode plane or several mode planes is/are stored in a memory belonging to the control unit; and in that the control unit is caused to control different laser sections such that the laser will obtain the desired operation point.

The invention also relates to means of the kind defined in Claim 12 and having the essential features set forth therein.

The invention will now be described in more detail with reference to exemplifying embodiments thereof and also with reference to the accompany drawings, in which

- Figure 1 is a partially cut-away, perspective view of a DBR laser;
- Figure 2 is a sectional view of a tuneable Grating Coupled Sampled Reflector (GCSR) laser;
- Figure 3 is a sectional view of a sampled grating DBR laser;
- Figure 4 is a diagrammatic illustration of mode planes in respect of phase current versus Bragg current;

- Figure 5 is a diagrammatic illustration of phase current versus Bragg current;
- Figure 6 is a diagrammatic illustration of delivered power versus tuneable current;
- Figure 7 illustrates wavelengths in a diagram of phase current versus Bragg current; and
- Figure 8 is a block schematic of an arrangement according to the invention.

As shown in Figure 1 is a DBR laser which includes three sections, i.e. a Bragg reflector 1, a phase section 2 and an amplifying section 3. Each section is controlled by injecting current into respective sections through the medium of respective electrical conductors 4, 5, 6.

Although the invention is described below mainly with reference to a DBR laser according to Figure 1, it will be understood that the invention is not restricted to any particular type of tuneable semiconductor laser. The invention can thus be applied with other tuneable lasers than those illustrated by way of example in the Figures.

Figure 2 is a sectional view of a tuneable Grating Coupled Sampled Reflector (GCSR) laser. Such a laser has four sections, namely a Bragg reflector 7, a phase section 8, a coupler 9, and an amplifying section 10. Each of the sections is controlled by injecting current thereinto.

Figure 3 is a sectional view of a sample grating DBR laser which also has four sections 11, 12, 13, 14, of which the sections 11 and 14 are Bragg reflectors and the sections 13 is a phase section, and section 12 is the amplifying section.

The aforesaid three types of laser are common. However, other types of lasers are also known to the art. As before mentioned, the present invention is not restricted to any particular type of laser.

When the tuning currents, i.e. the currents injected into the various sections, are changed, the wavelength of the laser, the suppression of sidemodes and the optical power of the laser will also be changed. In particular, the voltage across the active laser section will depend on whether the laser is located in a good operation point or close to a mode jump.

The laser will lase in a given mode for different combinations of tuning currents, and give rise to different generated powers and different wavelengths. For instance, if the Bragg current, i.e. the tuning current through the Bragg section, is swept, the laser will pass through a number of mode jumps. Each of these mode jumps causes an incremental change in the wavelength. Sidemode suppression is good between mode jumps, but poor at the instance of a mode jump. Consequently, the laser shall be caused to have an operation point that is well distanced from two mutually adjacent mode jumps.

The laser will also pass through a number of mode jumps when the phase current, i.e. the tuning current through the phase section, is swept.

Figure 4 is a three-dimensional diagram showing mode planes 15, 16, 17 as a function of phase current, Bragg current and amplification current. The laser operates stably in combinations of the three tuning currents that lie on a mode

plane. A mode jump occurs when moving from one mode plane to another. The laser can thus be operated so that combinations of the three tuning currents will lie on one mode plane. This results in a mode pure laser and in high sidemode suppression The wavelength also varies with said combinations and increases upwards and to the right along the mode planes shown in Figure 4.

Figure 6 is a diagram of the power delivered versus Bragg current, i.e. current through the Bragg section. When the Bragg current is swept and the mode jumps are passed through, there is obtained a discontinuous signal, or a signal whose derivative is discontinuous, both with respect to the power of the laser, as evident from Figure 6, and also with respect to the voltage across the active section.

These discontinuities coincide with discontinuous changes in transmitted wavelength and with the operation points when the laser is not mode-pure. The transmitted wavelength is dependent on the refractive index of the waveguide. The refractive index in question depends on the density of charge carriers in the waveguide, which, in turn, depends on injected current.

According to the invention, the control of the different laser sections 1, 2, 3 is effected by varying the currents injected thereinto. The laser 30 is caused to detect the significance of discontinuities that occur in conjunction with mode jumps in a signal delivered from a sensing device which is firmly connected to the laser. Control of the various laser sections 1, 2, 3 is effected by a control unit 31. Different control combinations and the prevailing signal

from the sensing device are sent to the control unit 31, wherewith the control unit is caused to detect the mode planes of the laser 30, and at least a part of one mode plane or several mode planes is caused to be stored in a memory 32 belonging to the control unit 31. The control unit 31 is also caused to control the different sections 1, 2, 3 of the laser 30, such that the laser will obtain a desired operation point.

According to one highly advantageous embodiment of the invention, the sensing device includes a monitor detector 36, which is firmly connected to the laser 30 and which is caused to measure the optical power output of the laser for different control combinations of the various laser sections 1, 2, 3, where a signal delivered by the monitor detector 36 at different control combinations in response to the laser power output is sent to the control unit 31.

Thus, by measuring the laser output power when, e.g., the Bragg current is swept, it is possible to identify good operation areas without needing to measure in a conventional manner the spectrum emitted by the laser, as mentioned above. Thus, the position of the mode jump is established by sweeping the tuning currents and reading the power emitted, despite not reading the laser spectrum in a conventional manner. The operation areas 18, 19, 20 between the discontinuities, i.e. the mode jumps, shown in Figure 6 are suitable in this respect. The laser is suitably operated at an operation point where the power is maximum with respect to the Bragg current.

According to a preferred embodiment, one or more suitable operation points for the mode plane is/are stored in said memory.

In simple terms, the present invention functions to cause the laser to characterise itself through the medium of the monitor diode and systematic control of the different laser sections, and to store said characteristics in the control unit, thereby enabling the control unit to control the laser so that it will operate in desired operation points.

Although there have been described above a number of diagrams that include phase current, Bragg current, amplifying current and wavelength, it will be understood that relationships other than, e.g., phase current versus Bragg current can be established and used to control a laser. This becomes more apparent when considering a laser other than DBR laser, for instance a laser that includes four sections. Because the invention is not restricted to a DBR laser, the inventive method also comprises making those measurements that are necessary in respect of a given type of laser to calculate the relationships that shall be used to control the laser concerned.

Figure 8 is a schematic illustration of an inventive arrangement in block form. The numeral 30 identifies a DBR laser that has three sections 1, 2, 3. The reference numeral 31 identifies a control unit that includes a memory 32, which in this case is of the RAM type. The control unit is of a known suitable kind and may include a microprocessor or some other known control electronics. Thus, the control unit functions to control the sections individually with respect to injected current, through the medium of conventional

current generators 33, 34, 35 connected to respective sections 1, 2, 3. The laser is provided with a conventional monitor diode 36 which is fixed relative to the laser and which constitutes said sensing device. The monitor diode is adapted to measure laser output power and to deliver to the control unit a signal corresponding to said power output, via a conductor 37.

According to one preferred embodiment of the invention, light emitted from the laser is measured with the aid of a monitor detector that is connected to the front end-surface 40 of the laser and/or its rear end surface 41. However, it is also possible to measure said power with a monitor diode along a light conductor that extends from the front end-surface of the laser or from its rear end-surface. The monitor detector may alternatively be fully integrated with the laser.

When the monitor detector is placed on the front end-surface of the laser, curves corresponding to those shown in Figure 6 are obtained. On the other hand, when the monitor detector is placed at the rear end-surface of the laser, a maximum in Figure 6 will, of course, be corresponded by a minimum.

This will not make it difficult for one skilled in this art to create software for controlling the control unit in accordance with the inventive method, for instance in providing a microprocessor with appropriate software.

There has been described in the aforegoing a first embodiment where the sensing device includes a monitor detector.

According to a second embodiment of the invention, the sensing device includes, instead, a sensing circuit which is adapted to detect the voltage that prevails across the different laser sections when different amounts of current are injected into said sections 1, 2, 3. The detection circuit is firmly connected to the laser and is caused to measure the voltage across the various laser sections 1, 2, 3 for different combinations of laser section control. Signals delivered by the detection circuit at different control combinations are sent to the control unit 31.

When the laser is controlled with current and the laser goes through a mode jump, a discontinuity will occur in the voltage across one or more of the laser sections.

According to a third embodiment of the invention, said sensing device includes a sensing circuit which is adapted to detect the current that flows through the different laser sections when a voltage is applied to said sections 1, 2, 3. The detection circuit is firmly connected to the laser and is caused to measure the current that passes through the various laser sections 1, 2, 3 with different combinations of voltage control across said sections. Signals delivered by the detection circuit in response to different control combinations are sent to the control unit 31.

It appears that when the laser is controlled with current and the laser goes through a mode jump, a discontinuity will occur in the voltage across one or more of the laser sections.

The circuit for detecting the voltage across the laser sections, or the current that passes therethrough, can be integrated in a known manner in the drive circuits 33-35 exemplified above as current generators. Alternatively, the detection circuits may be arranged separately.
In the above case in which the different laser sections are controlled by applying a voltage, the reference numerals 33-35 in Figure 8 designate conventional voltage generators.

An inventive arrangement can be considered as a laser module that includes a laser, a control unit, current or voltage generators, said detection device, etc., where the component parts are mounted on one and the same circuit board or like means.

According to one highly preferred embodiment of the invention, the control unit is caused to evaluate and store optimal laser operation areas in the form of single-dimensional curves corresponding to laser-section control combinations.

As will be evident from Figure 4, in the case of a DBR laser suitable operation areas are found on the mode planes, i.e. for certain combinations of phase current and Bragg current. For instance, the operation areas for a DBR laser can be described as single-dimensional curves in the plane comprised of phase current and Bragg current. Such single-dimensional curves, which form a part of the mode plane, are shown in Figure 5.

It is not necessary to know the wavelength of the laser in all applications, the only requisite being that the laser

operates stably and is mode-pure. This makes it unnecessary to establish the wavelength of the laser for the different operation points.

However, it is necessary in many applications to know precisely the wavelength transmitted. When the laser is controlled in accordance with said single-dimension curves, the wavelength transmitted by the laser is caused to be measured with an external instrument and the resultant measurement stored in the memory of the microprocessor, in accordance with a highly preferred embodiment of the invention. This greatly reduces the amount of information that need be stored in the memory of the microprocessor while enabling the laser to be controlled with great precision with respect to transmitted wavelength.

Figure 7 is a diagrammatic illustration given by way of example of phase current versus Bragg current, in the form of a single-dimensional curve. The Figure also shows how the wavelength varies along the curve. The wavelength is given in nanometers.

According to one preferred embodiment of the invention, the control unit is caused to execute a new characterisation of the laser at certain predetermined time intervals, and compare the values of the new characterisation with corresponding values obtained from an earlier characterisation. Thus, new operation areas will be detected in those cases when the working points of the laser have been shifted. Those curves that are measured in the first characterisation are shown in full lines in Figure 5, whereas the curves measured in a later characterisation are shown in

broken lines. Assume that the laser has operated along curve 39. As a result of the new characterisation, the corresponding curve has shifted so as to comprise the chain-line curve 39.

This embodiment is extremely beneficial, since it renders it unnecessary to dismantle a laser in operation in order to ascertain conventionally whether or not the laser has drifted, and when necessary calculate new operation areas and adjust the wavelengths.

According to another preferred embodiment, when the laser has given rise to changed values in comparison with an earlier characterisation, the control unit is caused to change the control of the laser sections, so as to correct the wavelength transmitted by the laser substantially to conform to the wavelength that prevailed according to the earlier characterisation.

In the example illustrated in Figure 5, the control unit is adapted to control the laser along curve 39, so as to compensate for shifting of the operation point by the laser in the plane phase current-Bragg current, and therewith bring the wavelength to the correct value.

As before mentioned, the wavelength is determined by the amount of current injected into the section. A degradation can take place in time in the relationship between wavelength and current, this degradation being liable to destroy the wavelength accuracy of the laser. This degradation occurs primarily in the relationship between current and refractive index, whereas the relationship between refractive index and wavelength can be considered constant.

As will be understood from the aforesaid, the laser module is able to discern its mode jumps itself. For instance, when the laser degrades, the relationship between current and refractive index changes, whereas the relationship between the states of the mode jumps and refractive index can be considered as constant. Thus, changes in wavelength at a given current combination can be related to changes in positions of the mode jumps.

Thus, the laser module is able to itself discern when its wavelength drifts, without measuring the wavelength. Furthermore, since the above relationships are known, the laser module is itself able to compensate for the fact that the current combination at which the laser will operate mode-pure at desired wavelengths must be changed relative to ageing of the laser. This results in a laser which remains stable over a very long period of time.

According to another preferred embodiment, the control unit is caused to activate an alarm indicator 42 when the laser has given rise to changed values in comparison with an earlier characterisation, and when the change exceeds a predetermined level. This alarm indicator may be a light-emitting diode arranged in connection with the laser, or the control unit may send a signal to a monitoring computer or the like via a conductor. This embodiment enables an operator to be informed directly of which laser or lasers shall be taken out of operation and replaced with a new laser or lasers.

According to one advantageous embodiment of the invention, the operation point of the laser can be optimised automatically by applying a control signal on one or more tuning sections. An example of such application is found in sensor applications in which the wavelength of the laser shall be subjected to a slight wavelength control, in the Angstrom order of magnitude. This control can then be super-positioned to a greater and slower wavelength control.

It is assumed in this case that the laser has an optimal operation point when the wavelength coincides with optimal reflex from the Bragg section of the laser. By applying a control signal to, e.g., the phase section, the wavelength of the laser will be controlled. Assume that the control is so small that no mode jump will take place. The power measured via the monitor detector varies with the phase current and will have an extreme value, which is a maximum or minimum value depending on the end-surface from which measuring took place, when the phase current is optimal. When the phase-current control is multiplied by the measured power, there is obtained a signal which discloses the extent to which the bias point of the phase section shall be moved, and in which direction.

It will be obvious that the present invention solves the problems mentioned in the introduction and provides a highly beneficial method and arrangement.

Although the invention has been described with reference to exemplifying embodiments thereof, the person skilled in this art will have no difficulty in applying the invention to

other types of lasers and therewith also in other types of laser applications.

The invention is therefore not restricted to the aforedescribed exemplifying embodiments, but can be modified within the scope of the accompanying Claims.

CLAIMS

1. A method of optimising the operation point of a laser, comprising characterising the laser and controlling the different laser sections, **characterised** by controlling the different laser sections (1, 2, 3) by varying the current injected into respective sections; causing the laser (30) to be sensed with respect to discontinuities occurring at mode jumps in a signal from a detection device firmly connected to the laser; effecting the control of the different laser sections (1, 2, 3) by means of a control unit (31); delivering different control combinations and the signal delivered from the detection device to the control unit (31); causing the control unit to detect the mode plane of the laser (30); storing at least a part of a mode plane or several mode planes in a memory (32) belonging to the control unit (31); and causing the control unit (31) to control different laser sections (1, 2, 3) such that the laser will obtain the desired operation point.

2. A method according to Claim 1, **characterised** in that the detection device includes a monitor detector (36) which is firmly connected to the laser (30) and which is caused to measure the optical power delivered by the laser at different control combinations of the different laser sections (1, 2, 3); and delivering to the control unit (31) a signal from the monitor detector (36) at different control combinations in relation to the power delivered by the laser.?

3. A method according to Claim 1, **characterised** in that said detection device includes a detection circuit (33-35) which functions to detect the voltage that prevails across

the different laser sections when different amounts of current are injected into said sections (1,2,3), said detection circuit being firmly connected to the laser (30); in that said detection circuit is caused to measure the voltage across the different laser sections (1, 2, 3) for different combinations of control of the different laser sections (1, 2, 3); and in that signals delivered from the detection circuit at different control combinations are sent to the control unit (31).

4. A method according to Claim 1, **characterised** in that said detection device includes a detection circuit (33-35) which is adapted to detect the current that flows through the different laser sections when voltage is applied to said laser sections (1,2,3), said detection circuit being firmly connected to the laser (30); in that said circuit is caused to measure the current through the different laser sections (1, 2, 3) for different voltage control combinations across the different laser sections (1, 2, 3); and in that signals delivered from the detection circuit at different control combinations are sent to the control unit (31).

5. A method according to Claim 1, 2, 3 or 4, **characterised** by storing one or more suitable operation points on the mode plane in said memory (32).

6. A method according to Claim 1, 2 or 5, **characterised** in that light emitted from the laser (30) is caused to be measured by a monitor detector (36) connected to the front end-surface (40) of the laser and/or to its rear end-surface (41).

7. A method according to Claim 1, 2, 3, 4, 5 or 6, **characterised** in that the control unit (31) is caused to evaluate and store optimal operation areas for the laser (30), in the form of single-dimensional curves corresponding to control combinations of the laser sections (1, 2, 3).

8. A method according to Claim 7, **characterised** in that when the laser is controlled in accordance with said curves, the wavelength transmitted by the laser (30) is caused to be measured by an external instrument (38) and the resultant value stored in the memory (32) of said control unit (31).

9. A method according to Claim 1, 2, 3, 4, 5, 6 or 7, **characterised** in that the control unit (31) is caused to execute a new characterisation of the laser (30) at certain predetermined time intervals, and to compare the values of the new characterisation with corresponding values from an earlier characterisation.

10. A method according to Claim 9, **characterised** in that when the laser (30) has given rise to changed values in comparison with an earlier characterisation, the control unit (31) is caused to change control of the laser sections (1, 2, 3) so as to correct the wavelength transmitted by the laser to correspond essentially to the wavelength that prevailed according to the earlier characterisation.

11. A method according to Claim 9 or 10, **characterised** in that when the laser (30) has given rise to changed values in comparison with an earlier characterisation and the change exceeds a predetermined level, the control unit (31) is caused to activate an alarm indicator (39).

12. An arrangement for optimising the operation point of a laser comprising characterisation of the laser and control of the different laser sections, **characterised** in that the arrangement includes a control unit (31, 33-35) which functions to control the different laser sections (1, 2, 3) by varying the injected currents; in that the arrangement further includes a detection device which is firmly connected to the laser (30) and which functions to sense the laser with respect to discontinuities that occur in a signal from the laser at mode jumps; in that the control unit (31) is adapted to store signals that disclose different combinations of control and the signal delivered from the detection device; in that the control unit is adapted to detect the mode plane of the laser (30); in that at least a part of one or more mode planes is/are stored in a memory (32) belonging to said control unit (31); and in that the control unit (31) is adapted to control the different laser sections (1, 2, 3) such that the laser will obtain a desired operation point.

13. An arrangement according to Claim 12, **characterised** in that said detection device includes a monitor detector (36) which is firmly connected to the laser (30) and which is adapted to measure the optical power output of the laser for different laser section control combinations (1,2,3); and in that signals emitted from the monitor detector (36) in response to the power output at different control combinations are sent to the control unit (31).

14. An arrangement according to Claim 12, **characterised** in that said detection device includes a detection circuit (33-35) which is adapted to detect the voltage that prevails across the different laser sections (1, 2, 3) when different

amounts of current are injected into said laser sections (1,2,3), said detection circuit being firmly connected to the laser (30); in that said detection circuit is adapted to measure the voltage across the different laser sections (1, 2, 3) for different laser section control combinations; and in that signals delivered from the detection circuit at different control combinations are sent to the control unit (31).

15. An arrangement according to Claim 12, **characterised** in that said detection device includes a detection circuit (33-35) which is adapted to detect the current that flows through the different laser sections when voltage is applied thereto, said detection circuit being firmly connected to the laser (30); in that said circuit is adapted to measure the current through the different laser sections (1, 2, 3) for different combinations of voltage control across the different laser sections (1, 2, 3); and in that signals delivered from the detection circuit at different control combinations are sent to the control unit (31).

16. An arrangement according to Claim 13, **characterised** in that light emitted from the laser (30) is measured with a monitor detector (36) connected to the front end-surface of the laser and/or to its rear end-surface.

17. An arrangement according to Claim 12, 13, 14, 15 or 16, **characterised** in that the control unit (31) is adapted to execute a new characterisation of the laser (30) at certain predetermined time intervals, and therewith compare the values of the new characterisation with corresponding values from an earlier characterisation.

18. An arrangement according to Claim 17, **characterised** in that when the laser (30) has given rise to changed values in comparison with an earlier characterisation, the control unit (31) functions to change the control of the laser sections (1, 2, 3) such as to correct the wavelength transmitted by the laser to essentially the wavelength that prevailed according to the earlier characterisation.

19. An arrangement according to Claim 17 or 18, **characterised** in that when the laser (30) has given rise to changed values in comparison with an earlier characterisation and the change exceeds a predetermined value, the control unit (31) functions to activate an alarm indicator (39).

Fig. 1

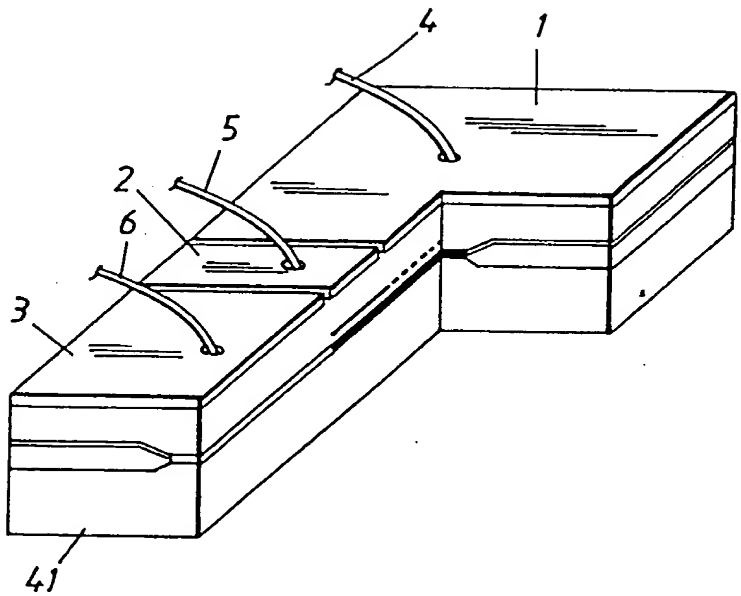


Fig. 2

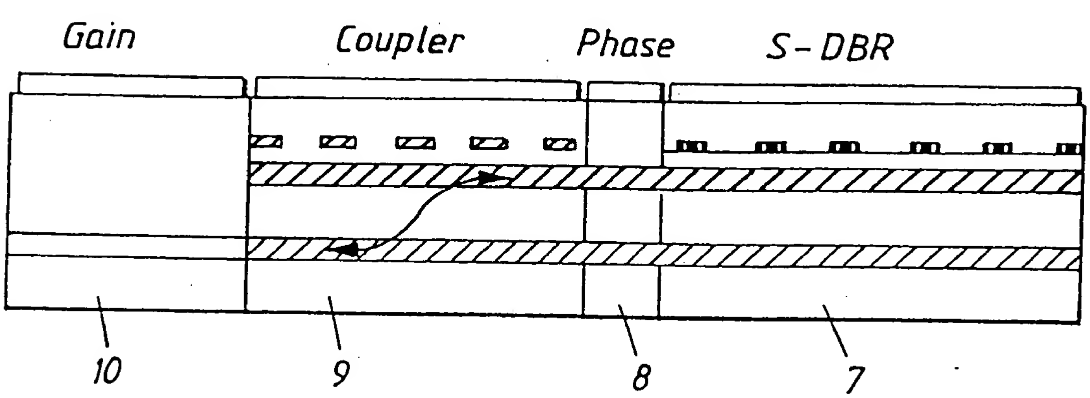


Fig. 3

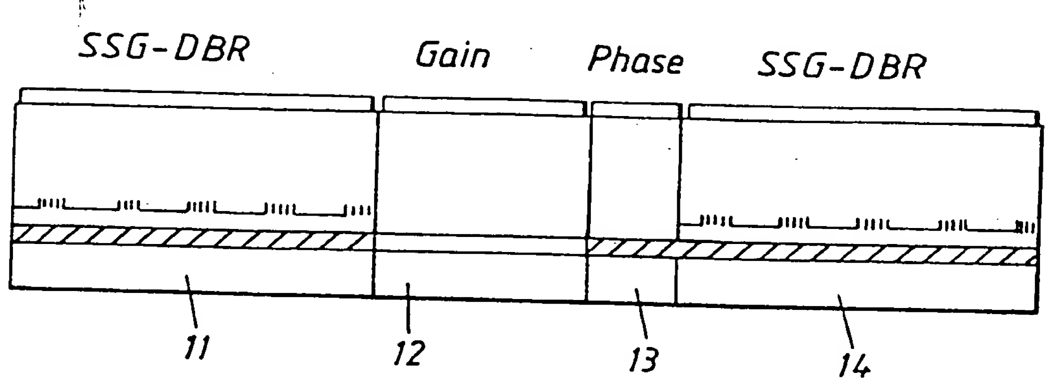

SSG-DBR
Gain
Phase
SSG-DBR
11
12
13
14

Fig. 4

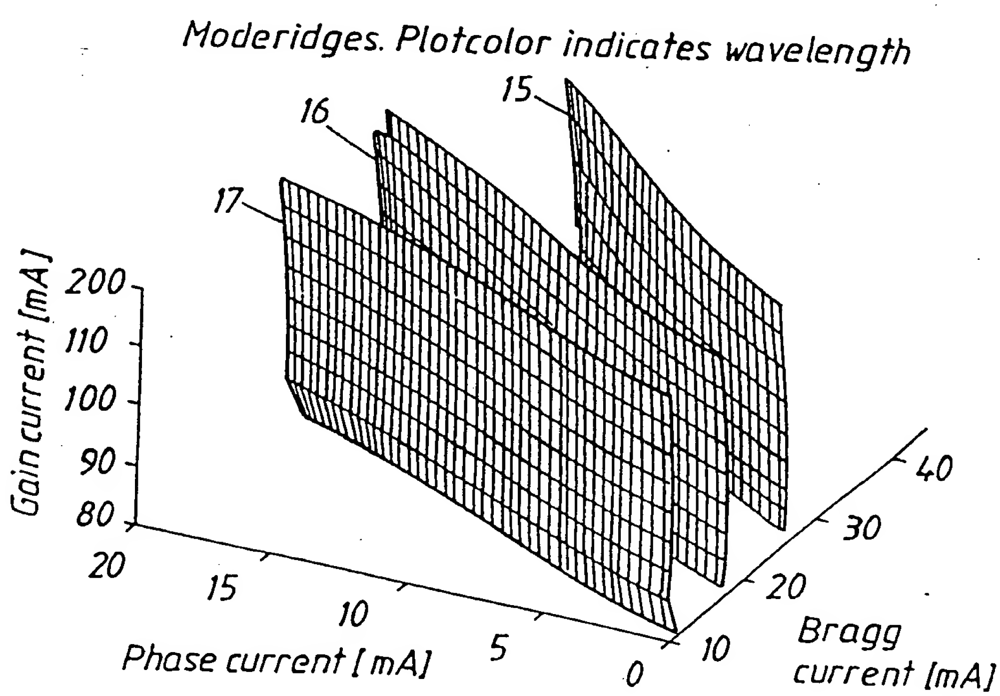

Moderidges. Plotcolor indicates wavelength
15
16
17
Gain current [mA]
200
110
100
90
80
20
15
10
5
0
Phase current [mA]
10
20
30
40
Bragg current [mA]

Fig. 5

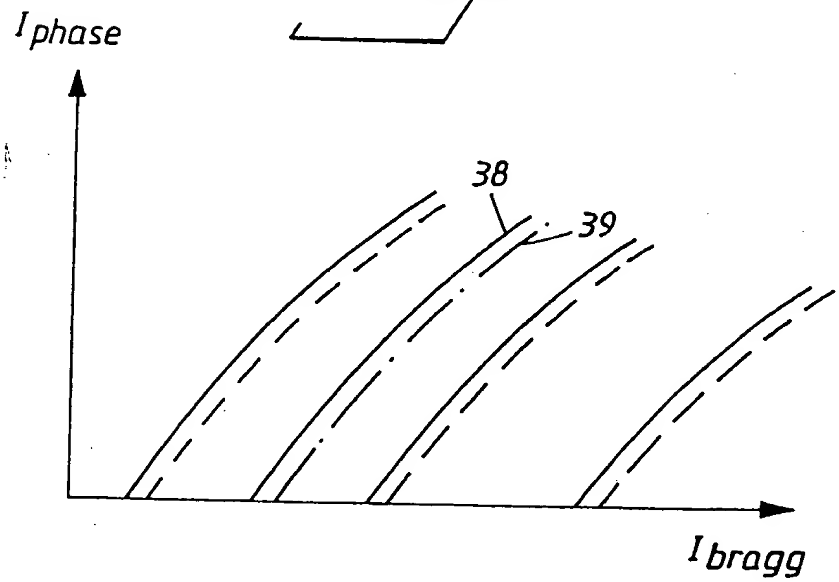

I phase
38
39
I bragg

Fig. 6

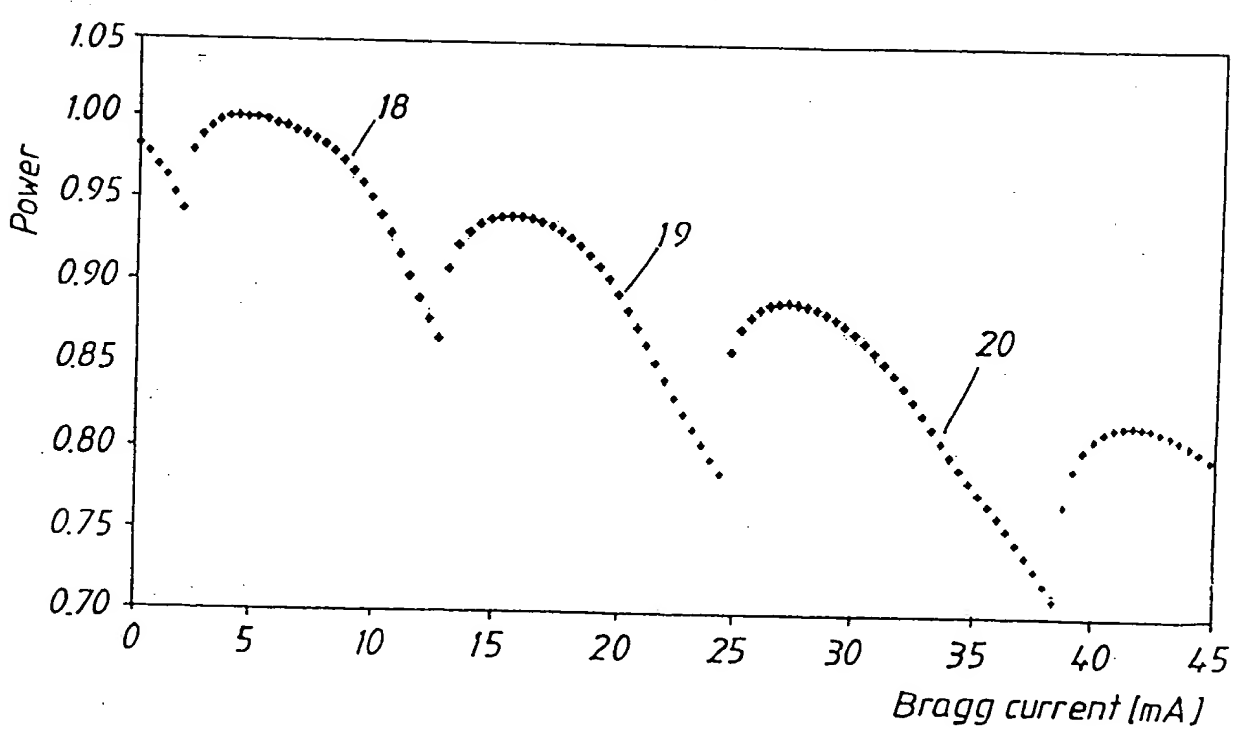

1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
Power
18
19
20
0
5
10
15
20
25
30
35
40
45
Bragg current [mA]

Fig. 7

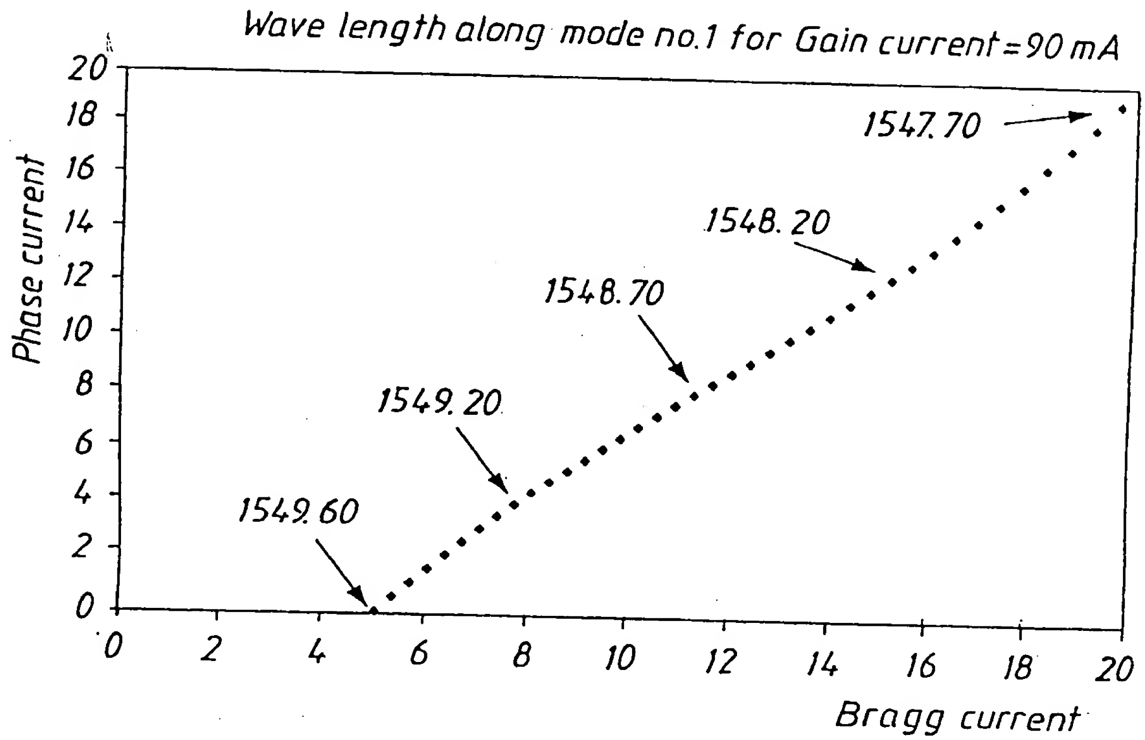
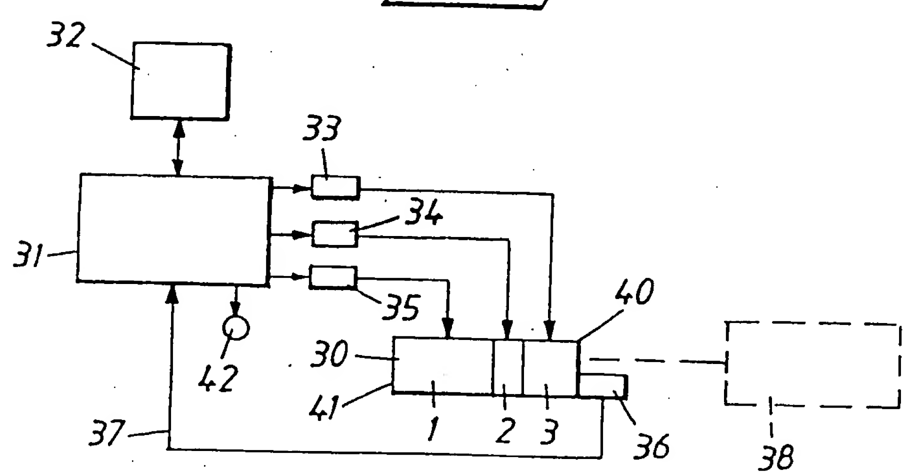

Wave length along mode no.1 for Gain current=90 mA
Phase current
Bragg current
0
2
4
6
8
10
12
14
16
18
20
1547.70
1548.20
1548.70
1549.20
1549.60

Fig. 8


32
33
34
35
31
40
30
41
42
1
2
3
36
37
38